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Influence of uniaxial pressure on the critical temperature for long delays in GaAs junction lasers

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In this work we report on the influence of uniaxial pressure applied perpendicularly to junction laser on the behavior of the critical temperature for the onset of long delays in GaAs junction lasers. Experimental data showing this influence for lasers operating in a TE or TM polarization are presented and explained on the basis of a thermal theory of long delays and related phenomena.

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In this work we report on the influence of uniaxial pressure on the behavior of the critical temperature for the onset of long delays[1] in Gallium Arsenide homojunction lasers. We have observed experimentally that depending on whether the laser mode is TE or TM polarized, the critical temperature decreases or increases with uniaxial pressure applied perpendicular to junction. This behavior of the critical temperature is opposite to that of the threshold current, which as a function of uniaxial pressure increases for a TE polarized mode and decreases for a TM polarized mode.[2,3] The dependence of critical temperature on uniaxial pressure is explained on the basis of our thermal theory of long delays and related phenomena.[4–6]

The apparatus used to apply uniaxial pressure is similar to the one described by us previously[2,3] except that it was miniaturized so as to be able to mount it on top of a copper cold finger, the lower part of which stays immersed in a bath of liquid nitrogen. The compressed gas introduced into the bellows in this case is helium instead of nitrogen. An inverted glass dewar placed over the cold finger provides a dry cold nitrogen gas atmosphere which prevents frosting. Two heaters, one controlled manually and the other automatically with thermocouple feedback, wound around the top of the copper cold finger, enable temperature variation of the laser in the range 80–300 K with a control of better than 0.5 K. A simplified illustration of this system is shown in Fig. 1.

The GaAs homojunction lasers used in our experiment were made by Zn diffusion into (100) oriented *n*-type GaAs substrates and had oxide stripe contacts of 12-μm width on the *p*-side. The lasers were excited with 100-ns current pulses at a repetition rate of 1 kHz. The light output was collected with a lens, analyzed with a polarizer, and detected with a photomultiplier which was used to determined the threshold current.

The critical temperature is defined as the temperature at which the time delay for the onset of lasing changes from a normal short delay to a long delay, and is accompanied by a sudden large increase in the threshold current above its normal exponential variation as a function of temperature.[1] Typical experimental results obtained by us are shown in Figs. 2 and 3. In Fig. 2 it is seen that for a laser operating in a TE mode the critical temperature decreases as uniaxial pressure is applied to the laser. The threshold current, as expected for TE polarization,[2,3] increases with uniaxial pressure at a fixed temperature. In Fig. 3 it is seen that for a laser operating in a TM mode the critical temperature increases with uniaxial pressure. The threshold current in this case, as expected for TM polarization,[2,3] decreases with uniaxial pressure at a fixed temperature.

The important thing to note in Figs. 2 and 3 is that the threshold current and the critical temperature change with uniaxial pressure in such a way that the threshold current at critical temperature, for different applied pressures, is very nearly the same.

In the thermal theory of Nunes *et al.*[4,5] for explaining the existence of long delays in homojunction and SH GaAs lasers, the basic mechanism for the onset of long delays is the breakdown of mode confinement that occurs in the internal asymetric waveguide of these lasers. This breakdown is caused by the lowering of the refractive index of the guiding (active) region by the presence of the injected free carriers. This decrease of the refractive index is to the carrier density where the lower refractive index step of the assymetric guide passes the critical value for confining a mode, guiding can no

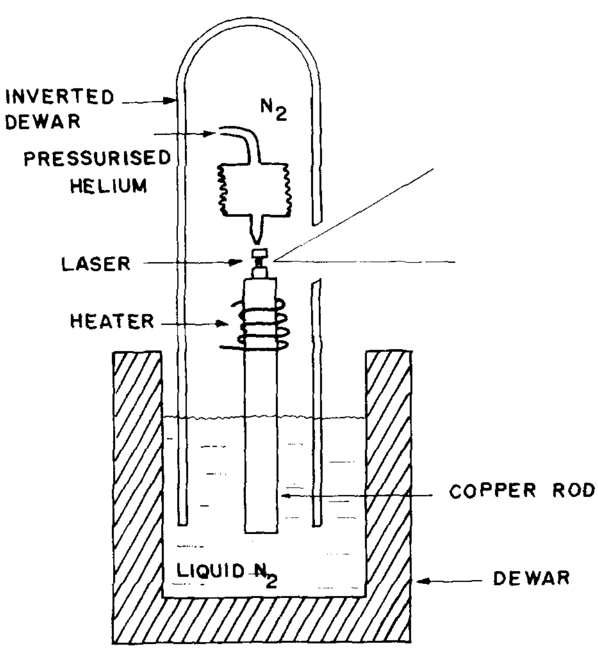

FIG. 1. Scheme of apparatus used to apply uniaxial pressure.

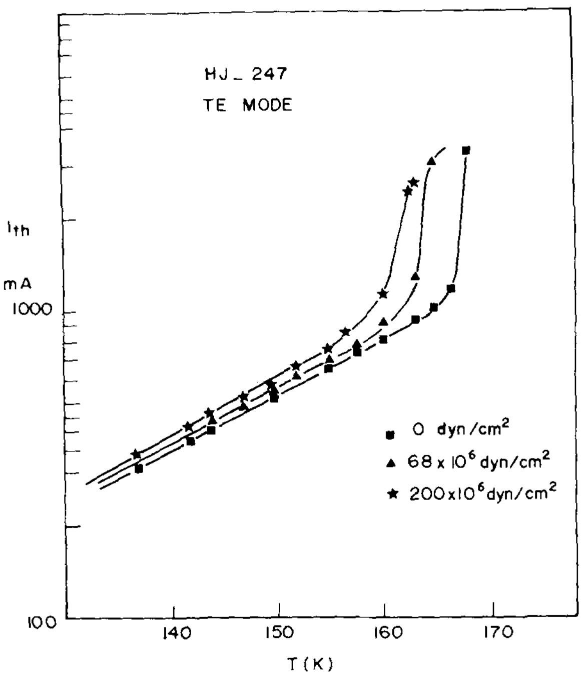

FIG. 2. Current threshold vs temperature for a laser operating in a TE mode and under different values of applied uniaxial pressure.

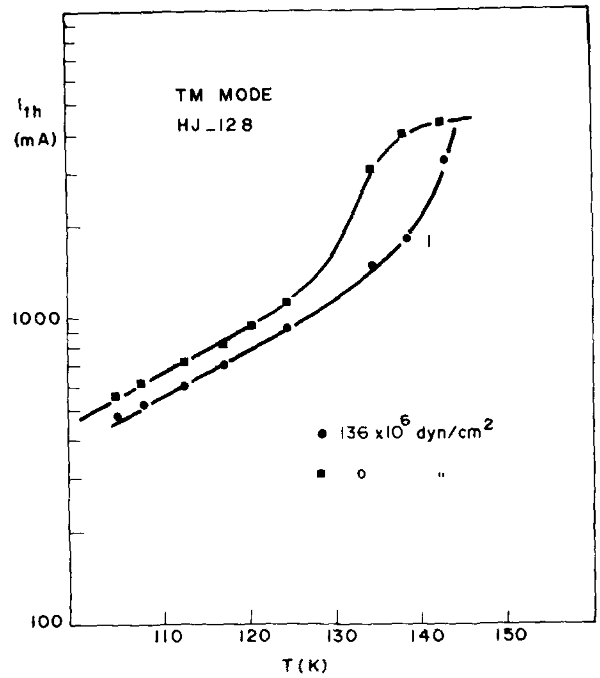

FIG. 3. Current threshold vs temperature for a laser operating in a TM mode and under different values of applied uniaxial pressure.

longer take place. Guiding is reestablished at a later time during the pulse as adiabatic Joule heating of the guiding region increases its refractive index; hence lasing with long delays. Gain guding confinement plays an essential role in helping oppose the effect of free carriers. (Our calculations[4,5] indicate that without the aid of gain guiding confinement, the thermal effect alone would not be sufficient to reestablish guiding.)

With this brief exposition of our theory the data of Figs. 2 and 3 can be easily explained qualitatively. For a given laser, with a given internal waveguide, there should exist a certain value of injected carrier density at which guiding should breakdown and the onset of long delays should take place. Up to threshold the injected carrier density is proportional to the current density. Hence for a given laser, there should exist a certain critical value of injection current density at which the onset of long delays should take place independently of other factors. This statement should hold reasonably well for small variations of temperature, but should be only approximately valid for large temperature variations because the proportionality between the injection current density and injected carrier density depends upon the recombination lifetime τ, which is a function of temperature,[7] and also the gain provided by a given carrier density is a function of temperature.

The temperature at which the threshold current density equals this critical injection current density will be the critical temperature. Since for a laser with a TE polarized mode, the threshold current density increases with uniaxial pressure, the threshold current density will equal the critical injection current density at lower temperatures for higher uniaxial pressures, resulting in a decrease of critical temperature with uniaxial pressure. The opposite should happen for a TM polarized mode. These conclusions are in agreement with the results of Figs. 2 and 3.

The conclusion we arrived at above, that for a given type of laser there should exist a certain critical injection current density at which the onset of long delays should take place, independently of other factors, is also able to explain the data observed by Ulmer and Hayashi[8] (Fig. 3, Ref. 8) that for SH lasers of different lengths made from the same wafer, the critical temperature is different, being higher for longer lasers, but the threshold current density at critical temperature is approximately the same.

In conclusion we have observed that when uniaxial pressure perpendicular to the junction is applied to GaAs homojunction lasers, the critical temperature for the onset of long delays decreases or increases with pressure depending on whether the laser mode is TE or TM polarized. The threshold current density at critical temperature stays approximately the same for different pressures. These results are explained by noting that for a given laser with a given internal assymetric waveguide, there should exist a certain critical injected carrier density, and hence a certain critical injection current density at which guiding should breakdown.

The temperature at which the threshold current density equals this critical injection current density should be the critical temperature.

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